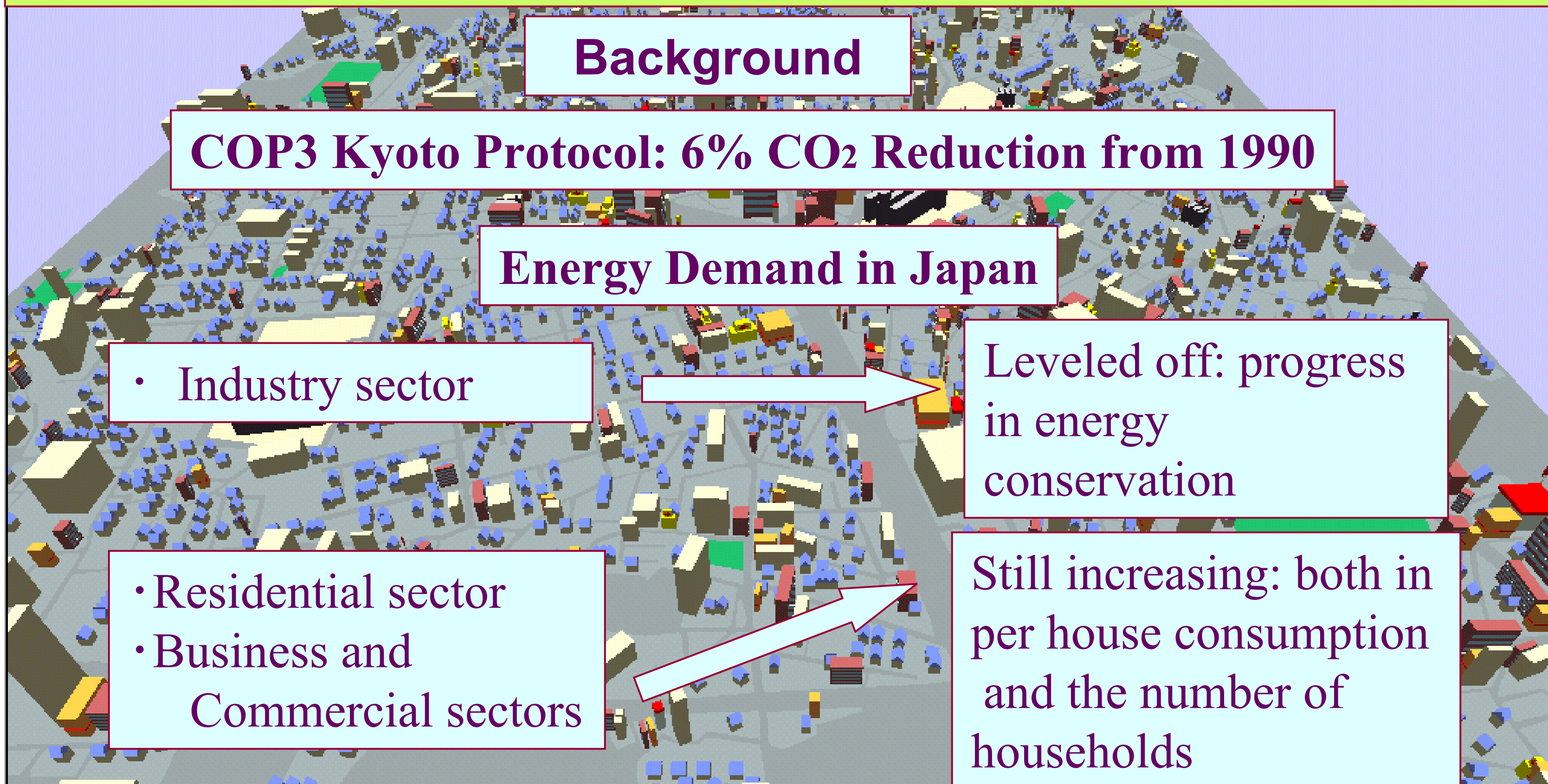
FRIENDS in the context of micro grid research



Background

COP3 Kyoto Protocol: 6% CO_2 Reduction from 1990

Energy Demand in Japan

- Industry sector

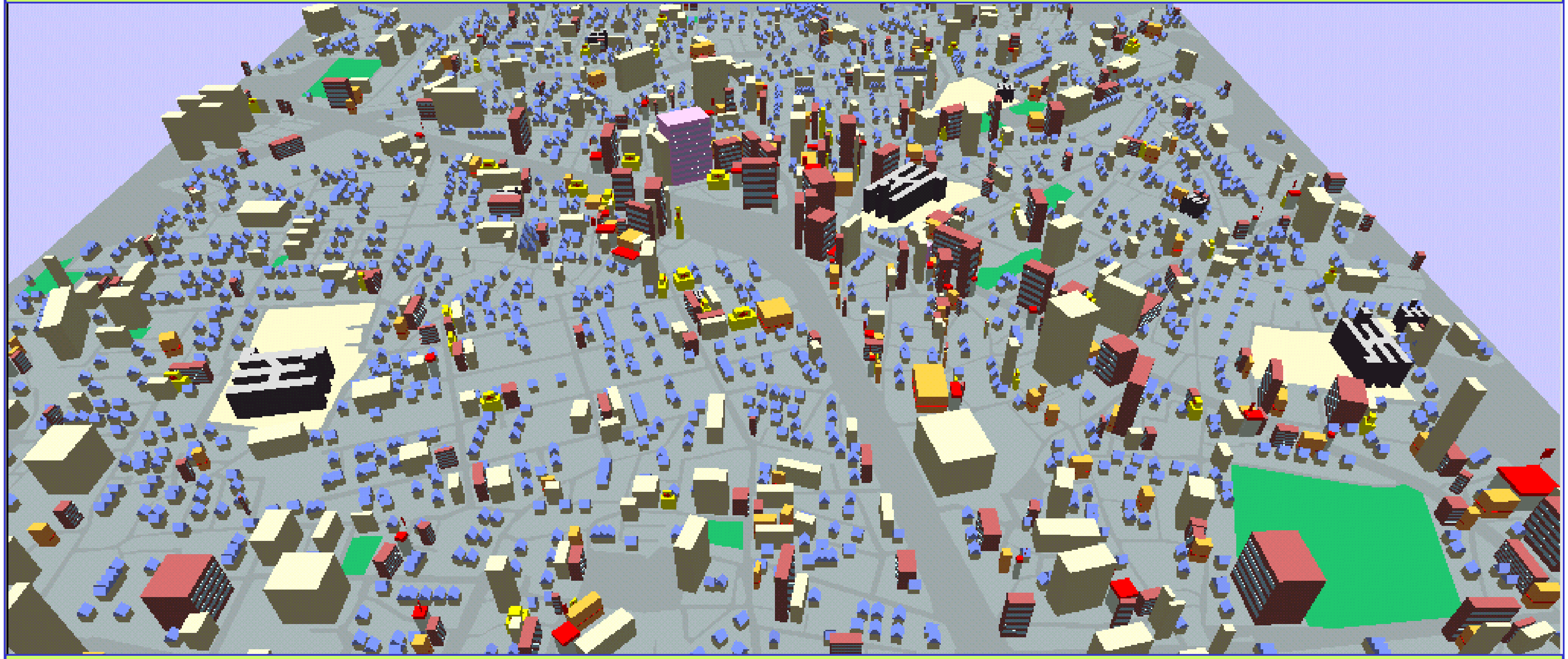
Leveled off: progress in energy conservation

- Residential sector
- Business and Commercial sectors

Still increasing: both in per house consumption and the number of households

Kiichiro Tsuji
Osaka University

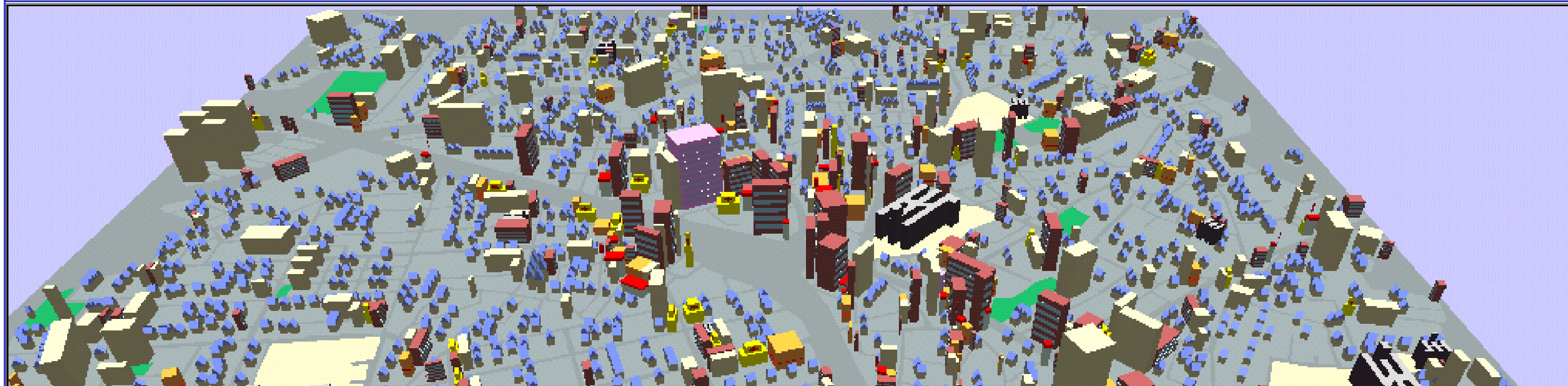
Analysis on energy systems in urban area

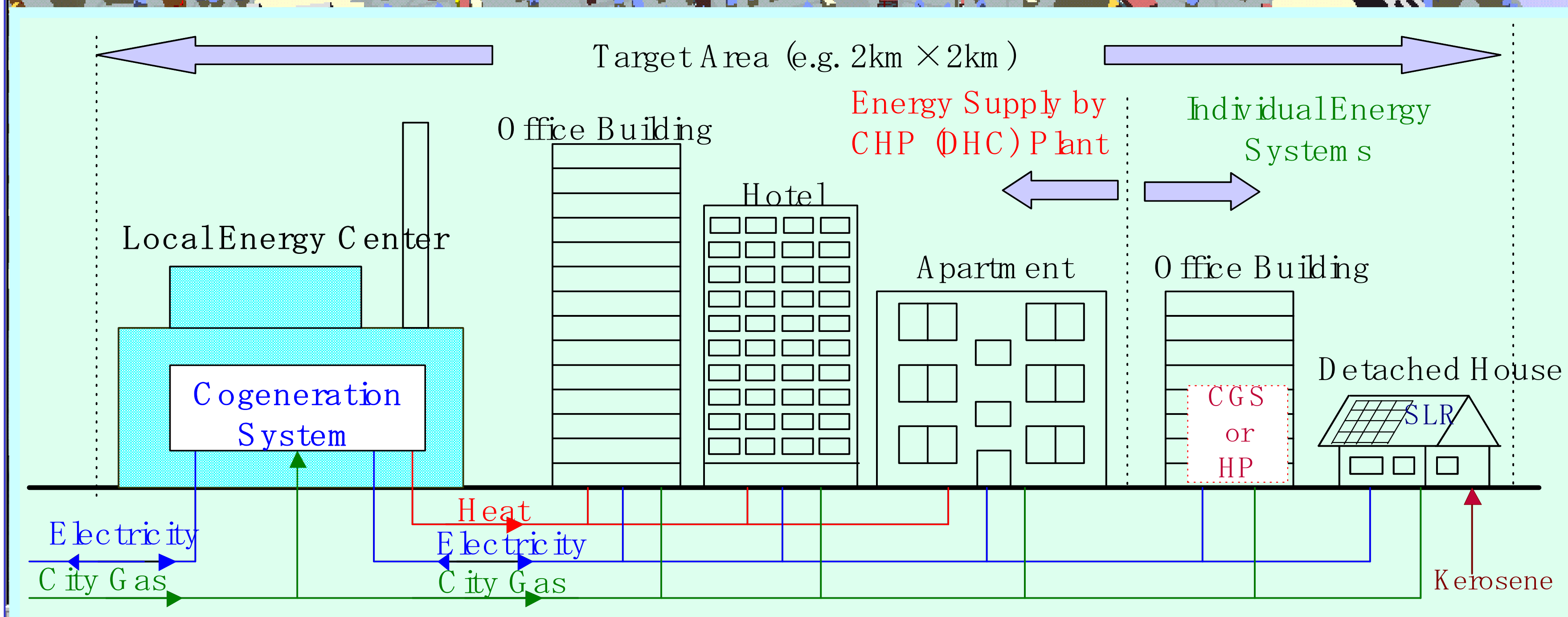


Search for "optimal " systems:
environmentally compatible energy efficient infrastructure

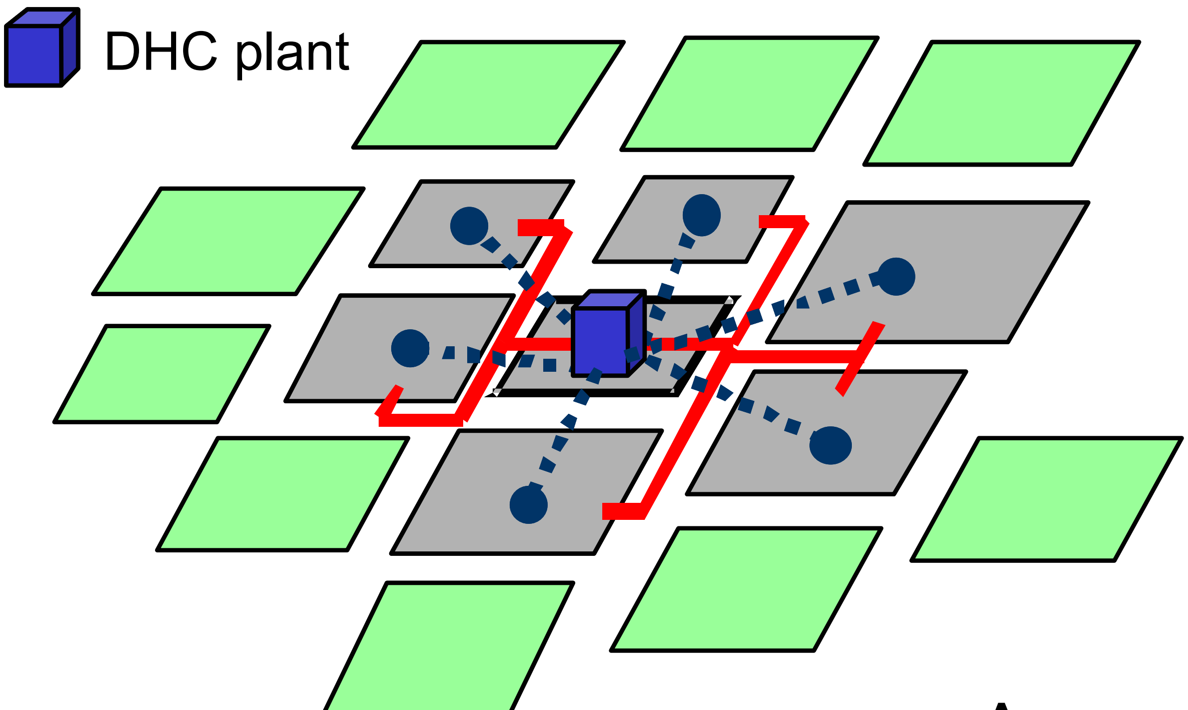
JSPS research project: 1997-2001
Handai Frontier Research Center research project: 2002-2004

Integrated energy service system and multiple objective optimization





Energy system optimization for specific area: Concepts of modeling



Facilities represented by floor space:
- Office buildings
- Hotels, Stores
- Restaurants
- Hospitals
- Detached Houses
- Apartments

Energy systems represented by discrete options

Area purchases electricity, city gas and kerosene

Piping network (Simplified)

Piping network (Detailed)

Areas with district heating and cooling System

Areas with individual energy systems

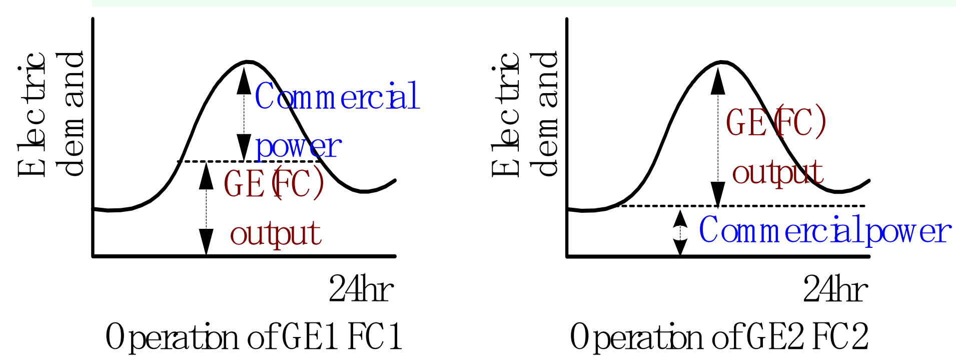
Energy system options

(a) Residential Houses

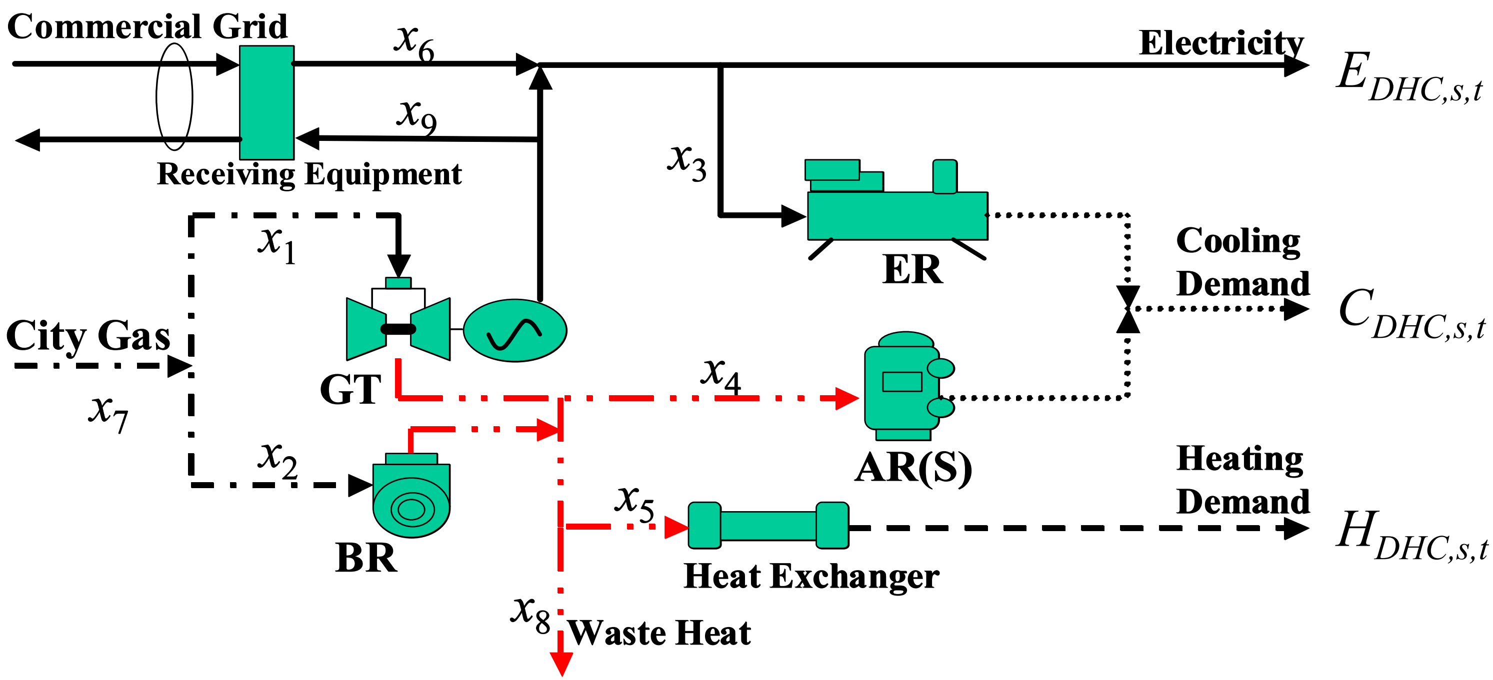
Symbols	Components
CNV	Air-conditioner + Stove + Gas boiler
SLR	CNV + Solar generation system + Solar-type water heater
ELE	Air-conditioner +Electric water heater + Electric cooking appliance
DHC	DHC(District Heating & Cooling)

(b) Business & Commercial Buildings

Symbols	Components
ARH	Absorption refrigerator and heating unit
ER	Electric turbo refrigerator + Boiler
GE1, GE2 FC1, FC2	Electric turbo refrigerator + Boiler + CGS(FC or GE) + Absorption refrigerator
HP	Heat pump system with heat accumulation equipment
DHC	DHC(District Heating & Cooling)



DHC plant configuration and constraints



$$
\left.
\begin{aligned}
&\eta_{gt}^{e} \cdot x_{1,s,t} + x_{6,s,t} - x_{9,s,t} = E_{DHC,s,t} + x_{3,s,t} \\
&\eta_{er} \cdot x_{3,s,t} + \eta_{ar(st)} \cdot x_{4,s,t} = C_{DHC,s,t} \\
&\eta_{hc} \cdot x_{5,s,t} = H_{DHC,s,t} \\
&\eta_{gt}^{h} \cdot x_{1,s,t} + \eta_{br} \cdot x_{2,s,t} = x_{4,s,t} + x_{5,s,t} + x_{8,s,t} \\
&x_{7,s,t} = x_{1,s,t} + x_{2,s,t}
\end{aligned}
\right\}
$$

Energy flow constraints in DHC plant

Multiple objective linear optimization model

Developed by Sugihara & Tsuji

Evaluation Indices:

- Cost
- Primary Energy Consumption
- CO_2 Emission

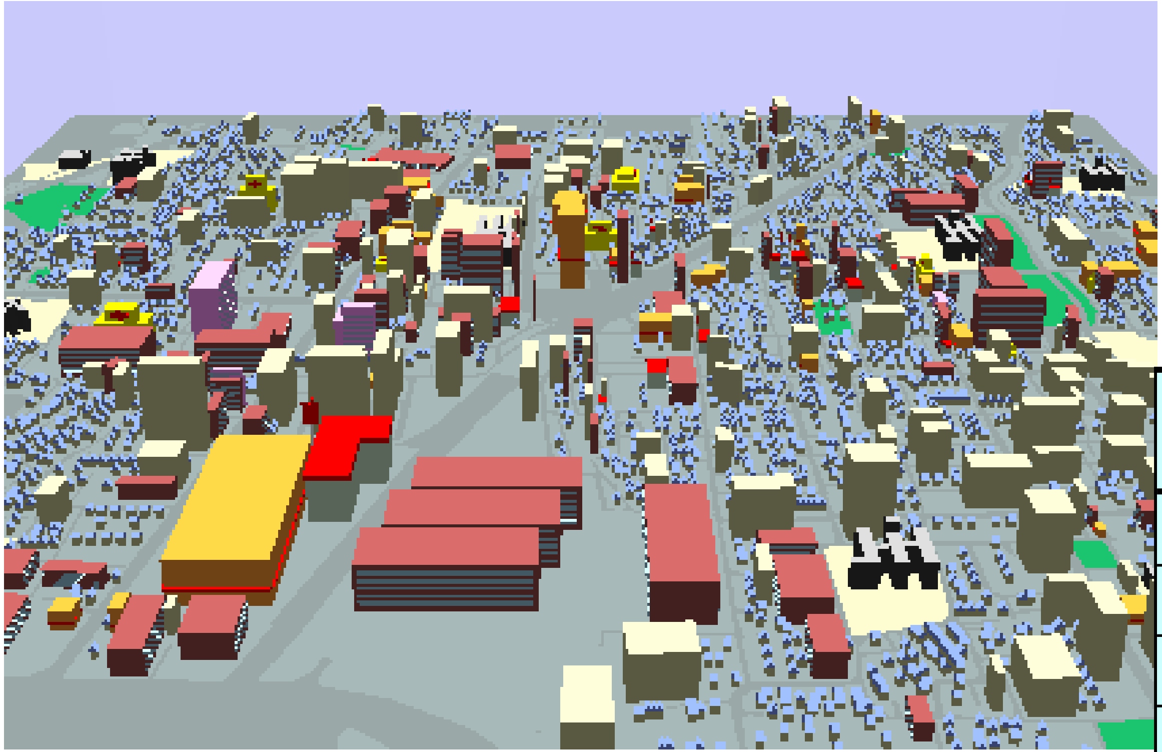
Variables:

- Share of energy system options
- Capacity and operational strategy for DHC co-generation plant

Reference Scenario

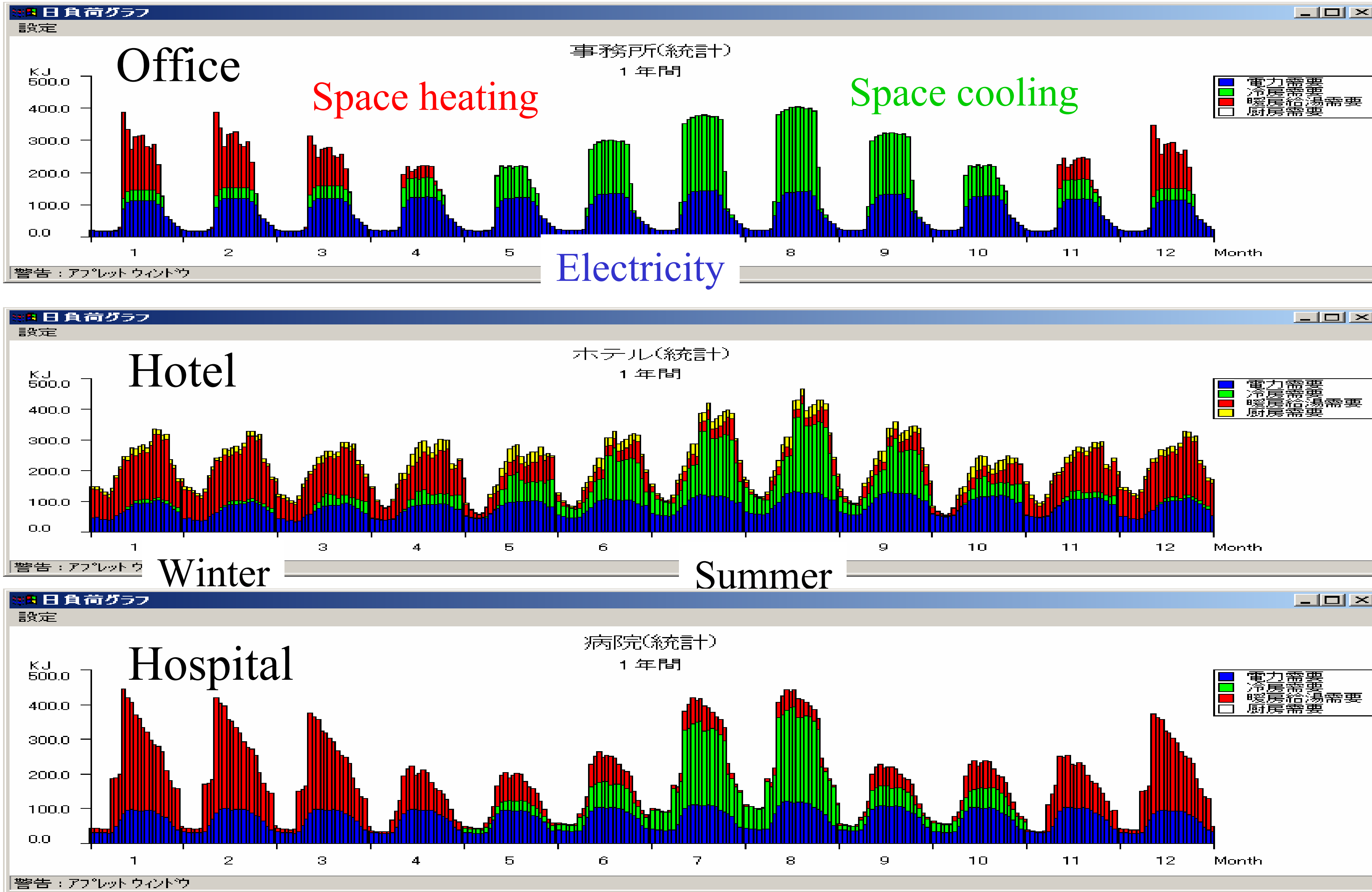
Office	ARH(24.4%) ER(75.64%)
Hotel	ER
Hospital	ER
Retail Store	ER
Restaurant	ER
Detached House	CNV
Apartment	CNV

Input data: Area for study

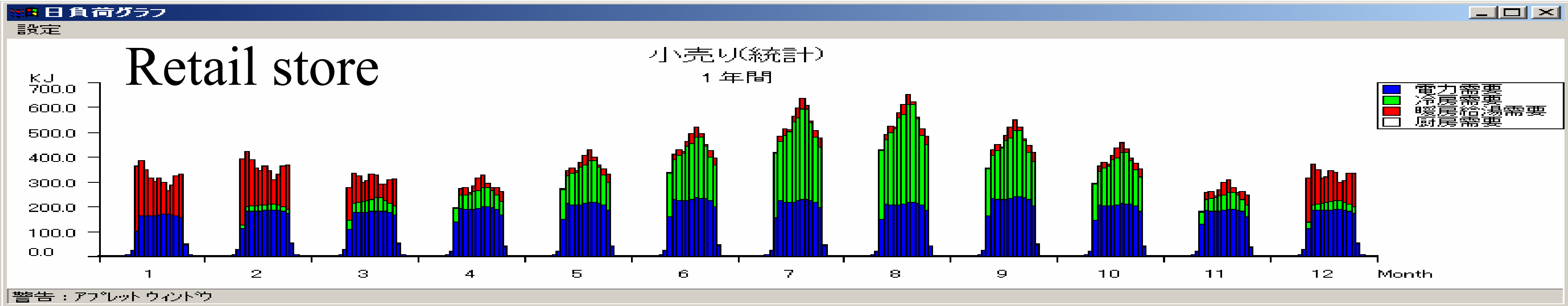


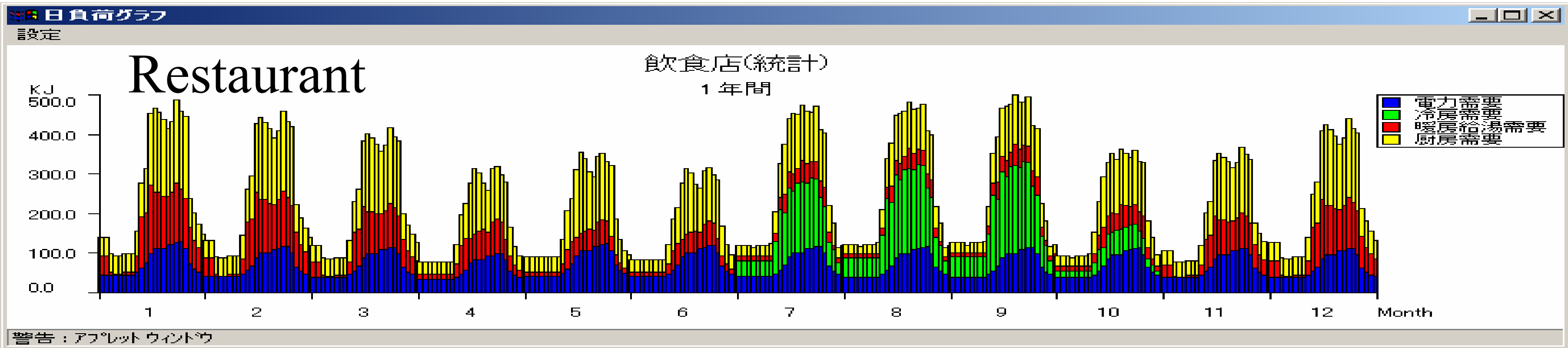
	Floor area [m^2]
Office	807,610
Hotel	58,349
Hospital	54,743
Retail store	281,219
Restaurant	53,780
Detached house	1,250.973
Apartment House	879,753

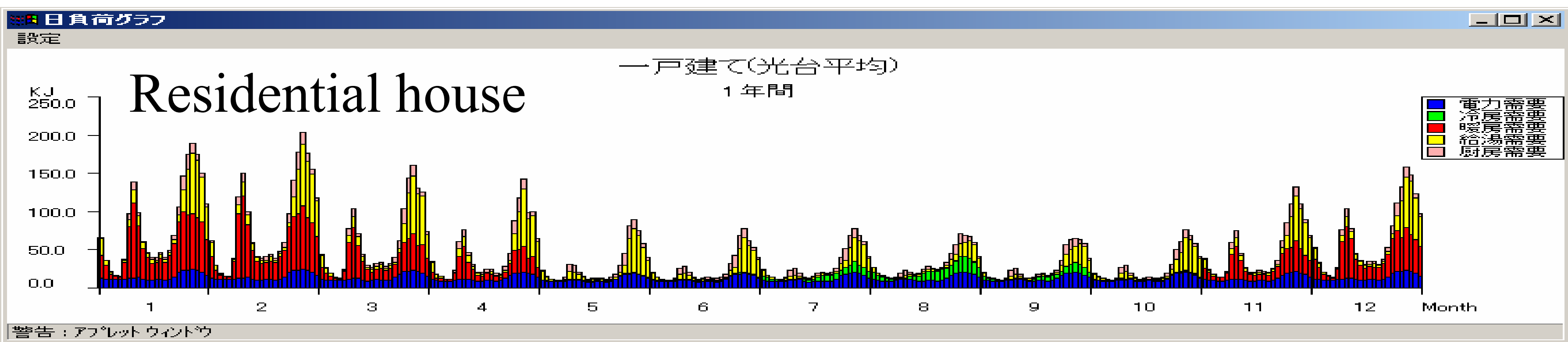
Input data: End-use energy demand for 12 representative days



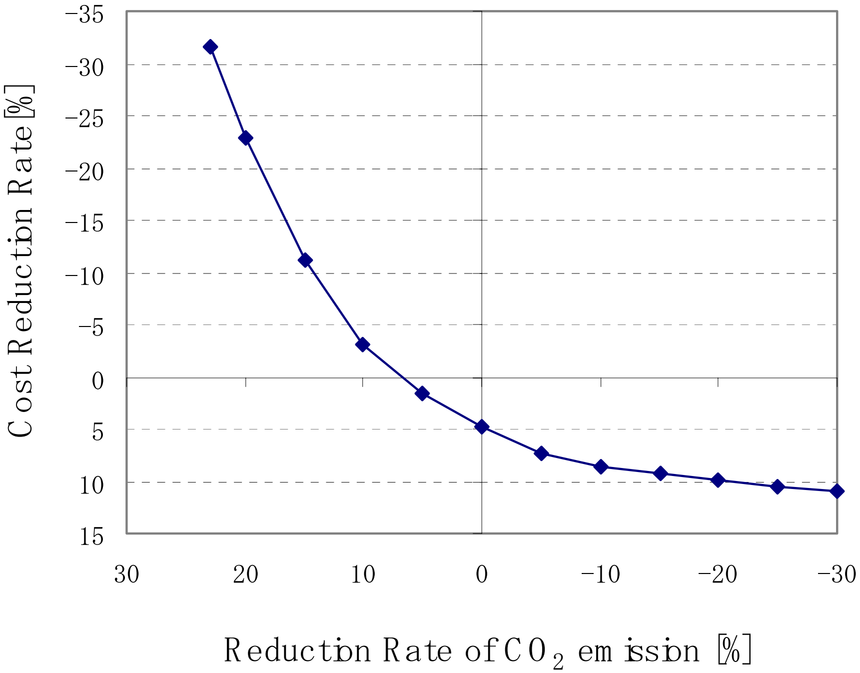
Input data: End-use energy demand for 12 representative days





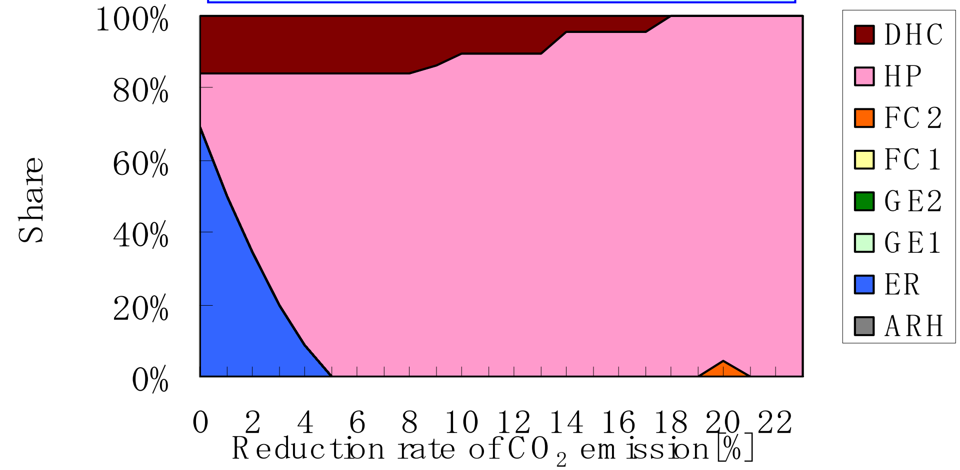


Tradeoff curves: Cost vs. CO_2 emission

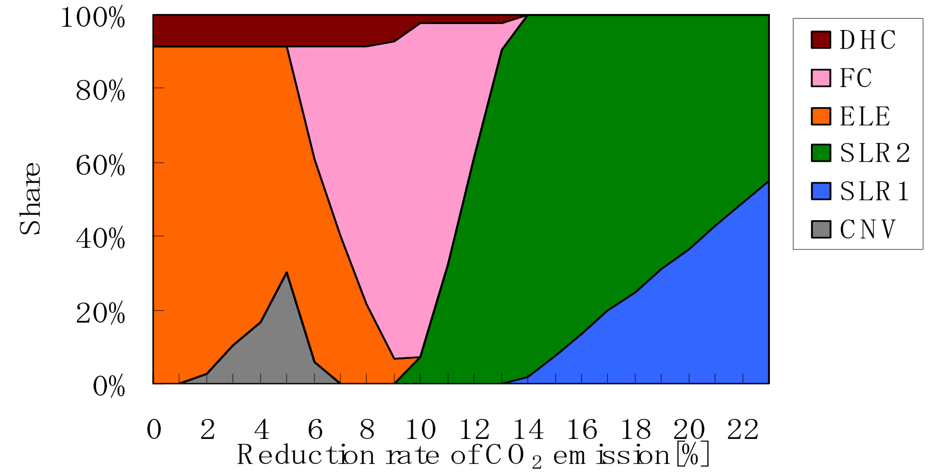


a) Tradeoff Curve

Share of energy system options



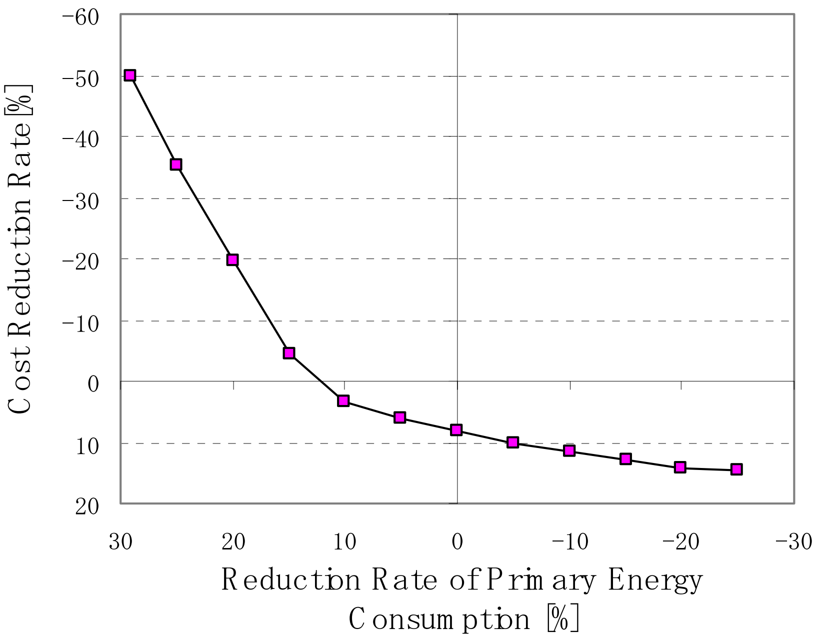
b) Business & Commercial Sector



c) Residential Sector

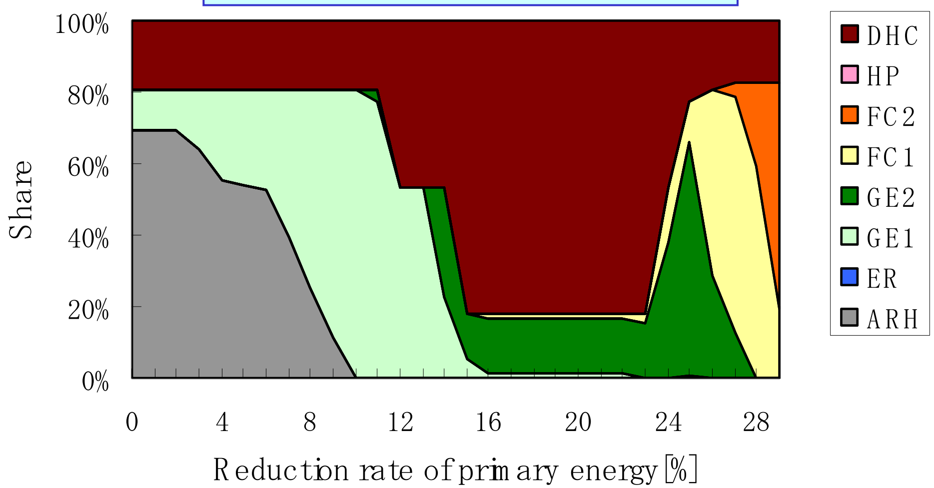
Distributed generation will increase as CO2 constraint get more severe

Tradeoff curves: Cost vs. Primary energy consumption

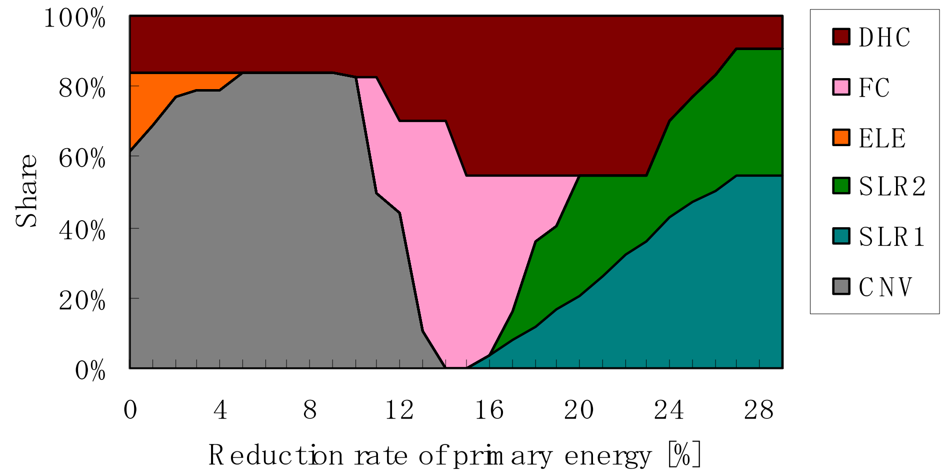


a) Tradeoff Curve

Share of energy system options



b) Business & Commercial Sector



c) Residential sector

Distributed generation will increase as primary energy constraint get more severe

Needs for new electric energy delivery system

[1] Penetration of Distributed Generation
- Photovoltaic
- Wind
- Micro Cogeneration

Reverse power problem
Frequency fluctuation
Voltage rise in distribution line
Protection problem in distribution system

[2]
- Deregulation of Electricity Market
- Diversification of Customer Needs

Unbundled power quality service
- uninterruptible power
- lower-price power

Quality of Power

Definitions of Events by IEEE Std.1159-1995

Voltage Stability

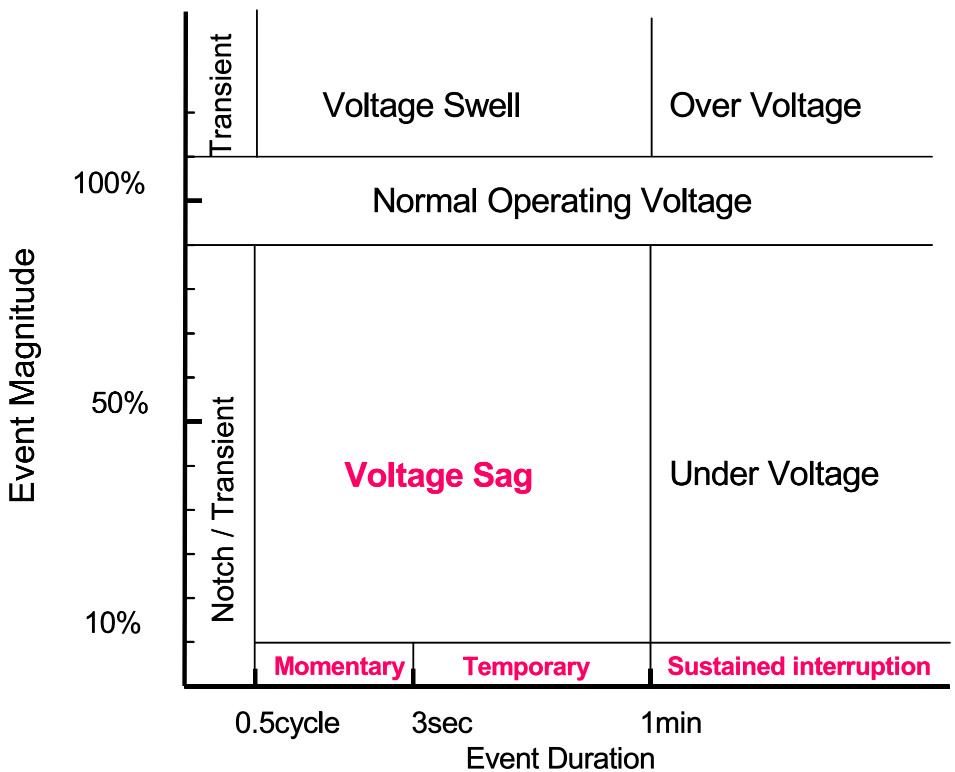
- **Under-voltage & Over-voltage**
- **Voltage Sag**
- **Voltage Swell**
- **Phase Shift**
- **Flicker**
- **Frequency**

Continuity of Supplying Power

- **Momentary Interruption**
- **Temporary Interruption**
- **Sustained Interruption**

Voltage Waveform

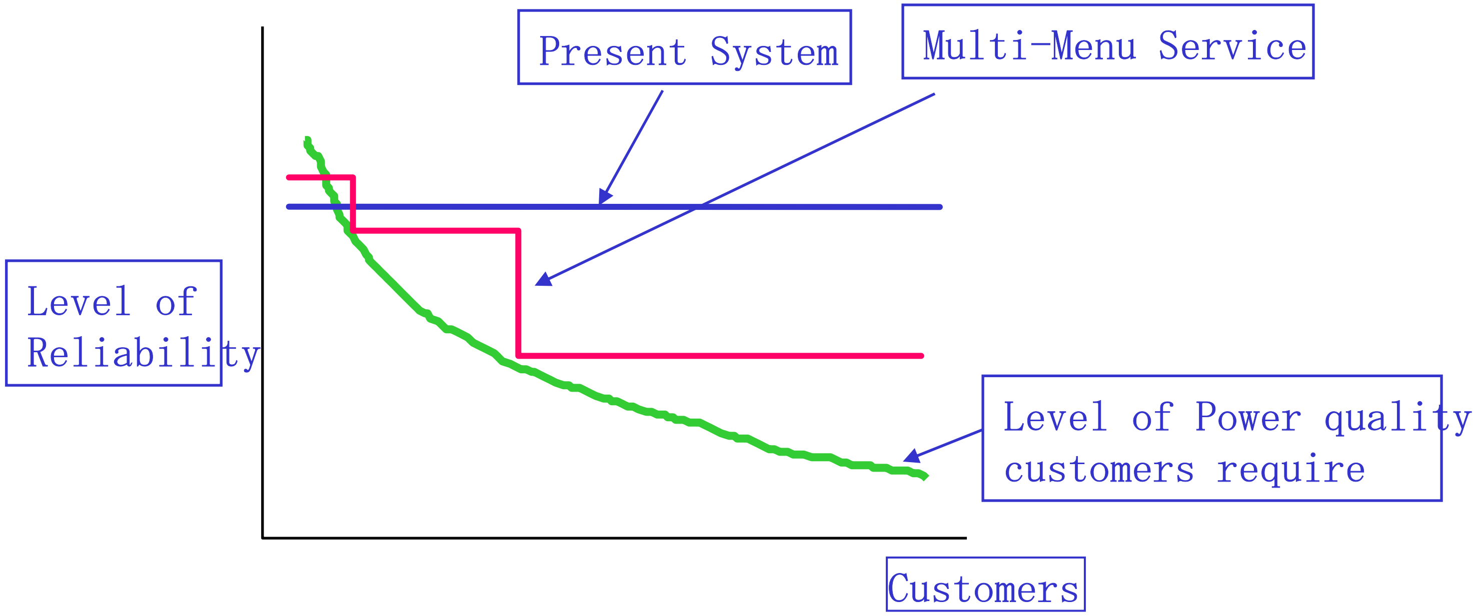
- **Transient**
- **Three Phase Voltage unbalance**
- **Harmonic Voltage, Current**
- **Notch**



Customer Needs

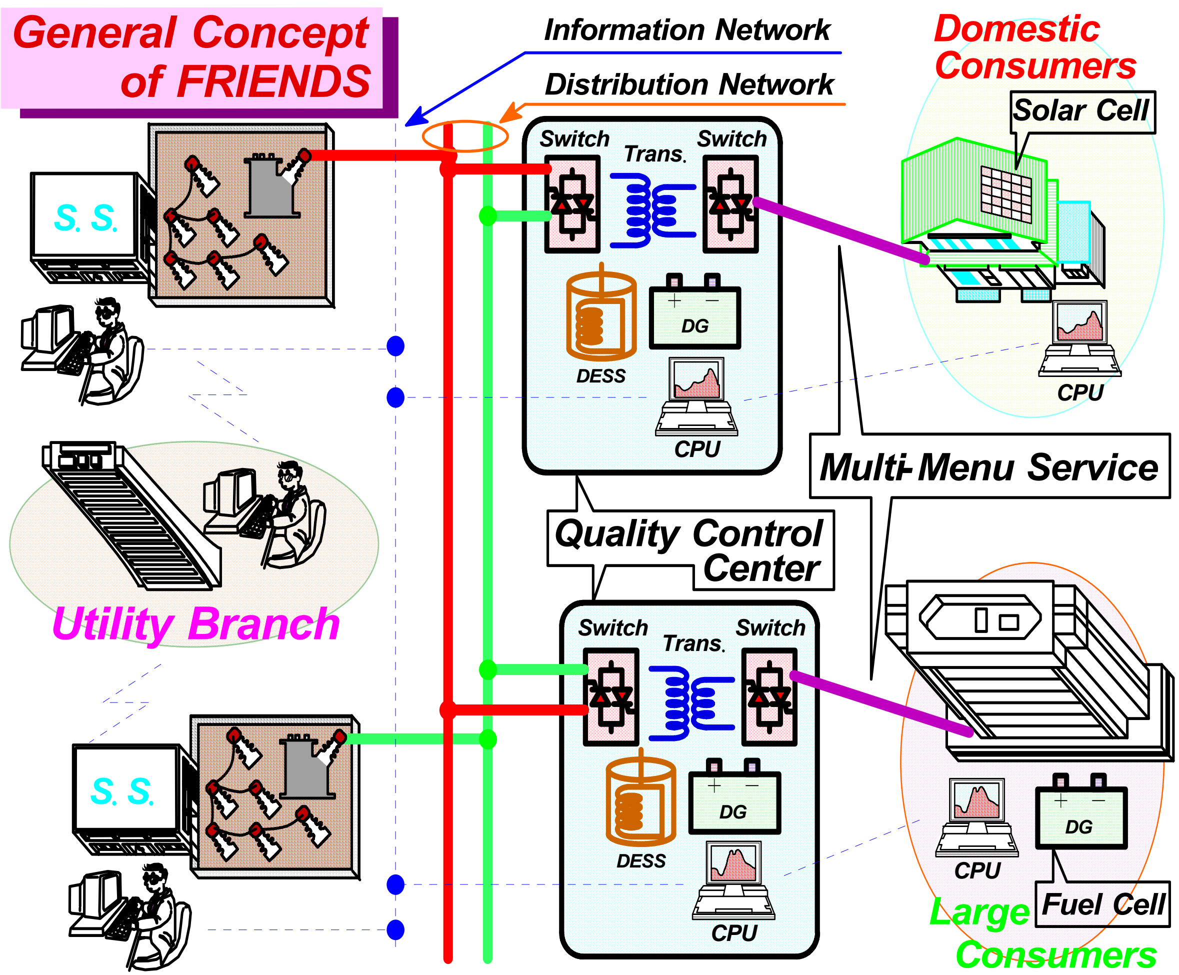
Does every customer request very high quality in power supply？
What if a customer can choose power of different quality with differen

⇨Power system configuration that allows a customer to choose.
⇨Can be realized by the use of power electronics



Concept of FRIENDS

Prof.Hasegawa、Prof.Nara 1994



FRIENDS

By use of QCC(Quality Control Center)

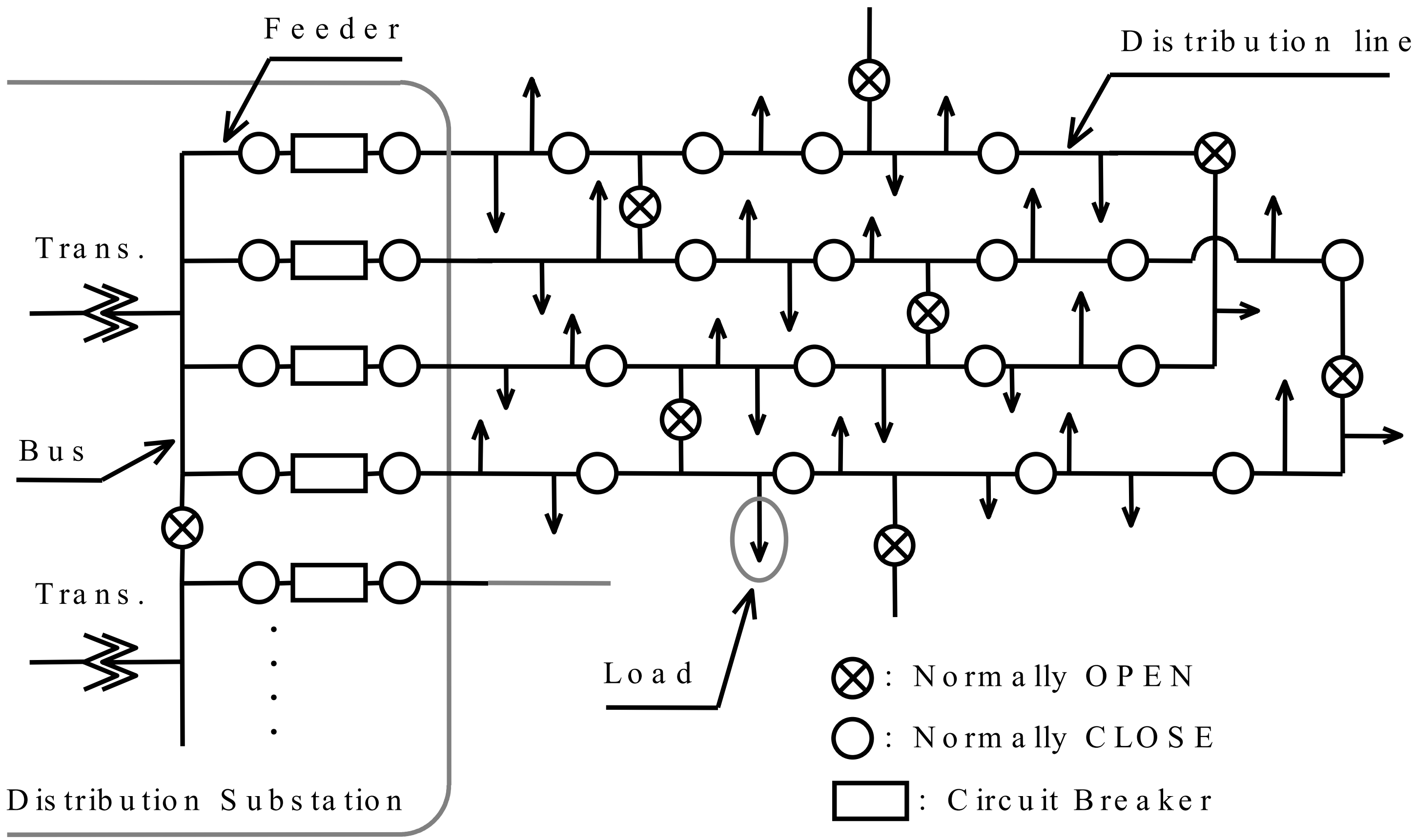
[1] Several qualities of power are supplied to customers.

[2] Unbalance and harmonics current from loads are compensated.

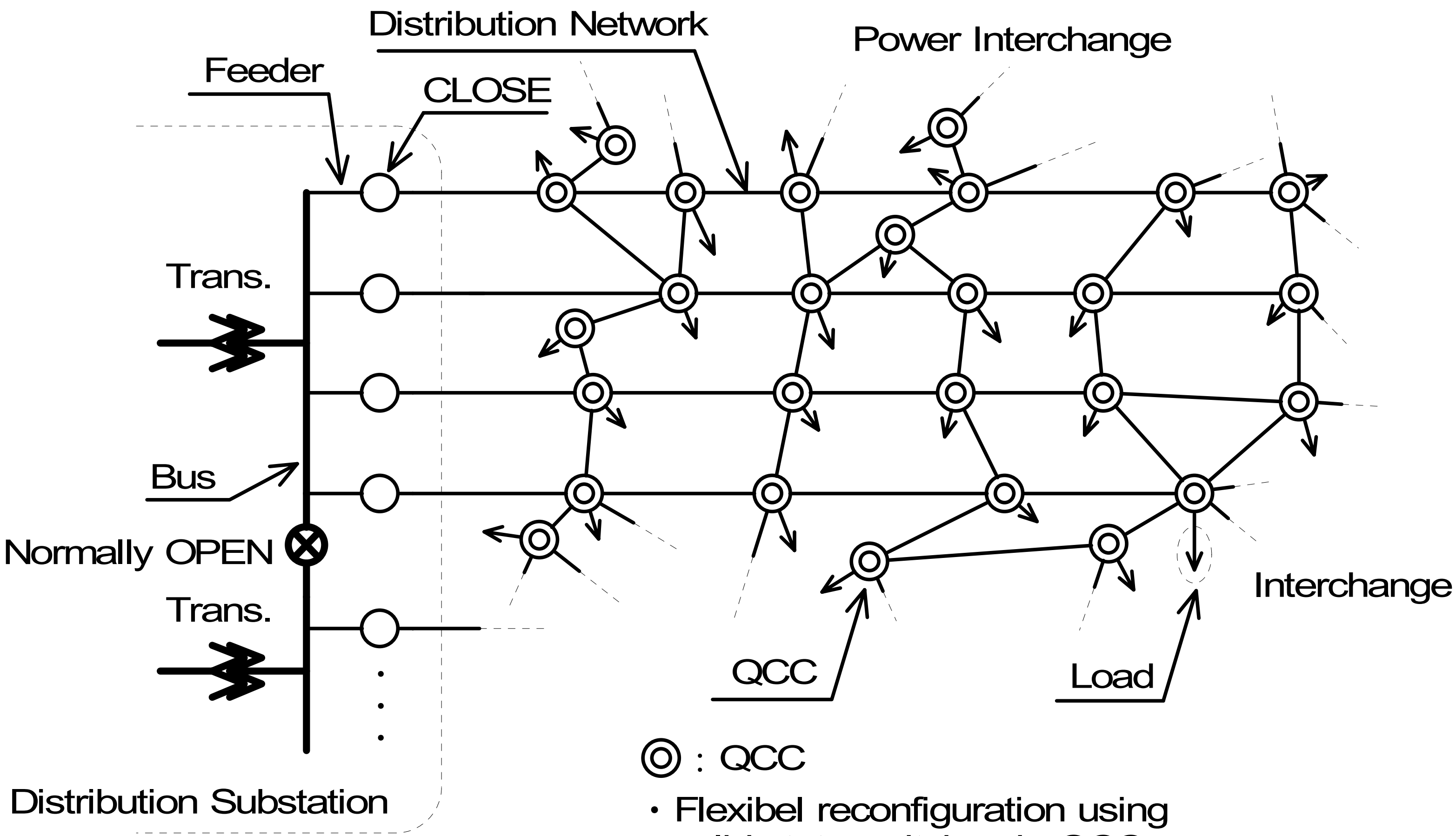
[3] Power fluctuation from distributed generators (DG) and loads is compensated, and reverse power from DGs is absorbed.

(Flexible Reliable and Intelligent Electrical eNergy Delivery System)

Conventional Radial Distribution Network

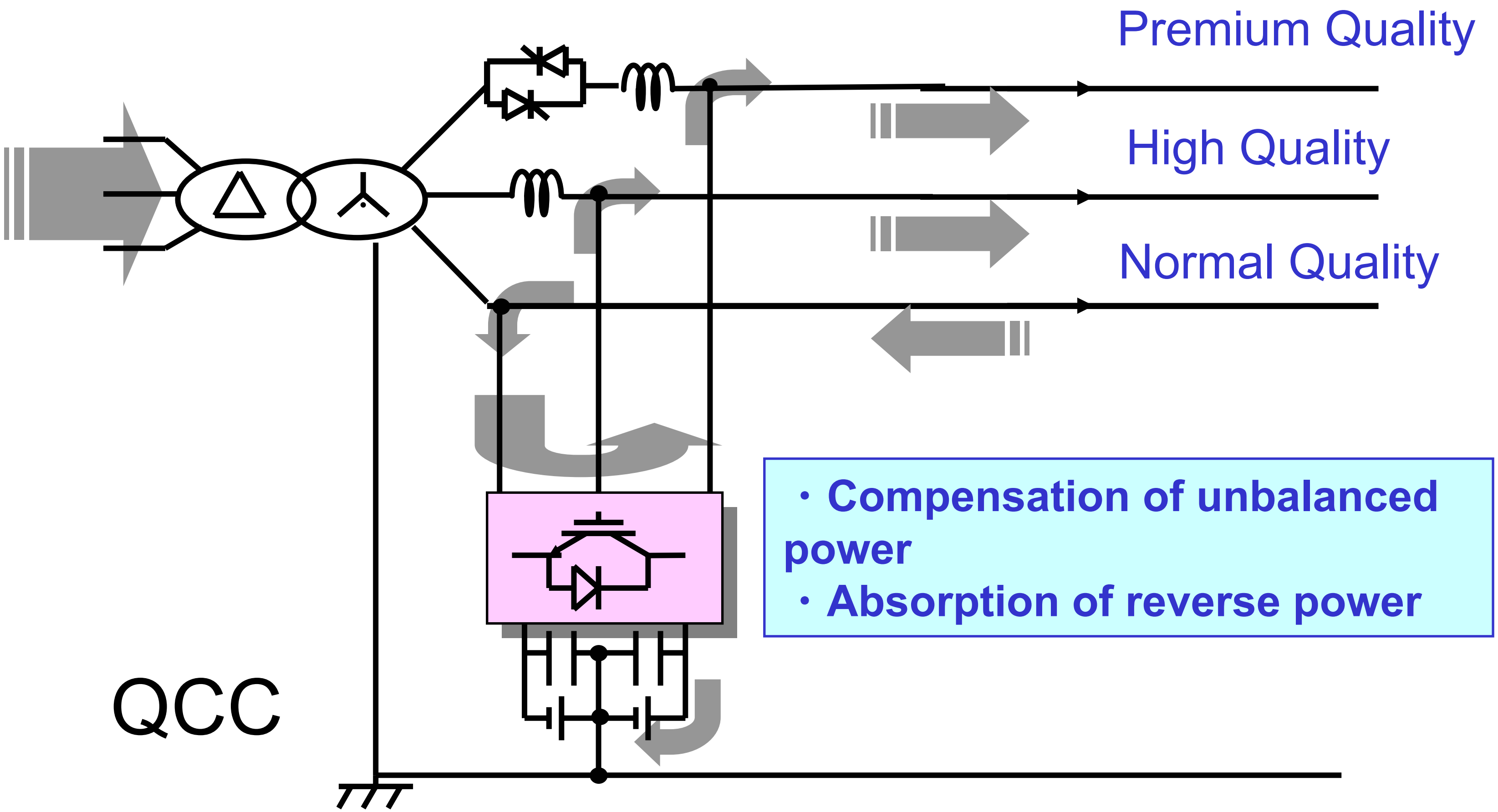


FRIENDS Network



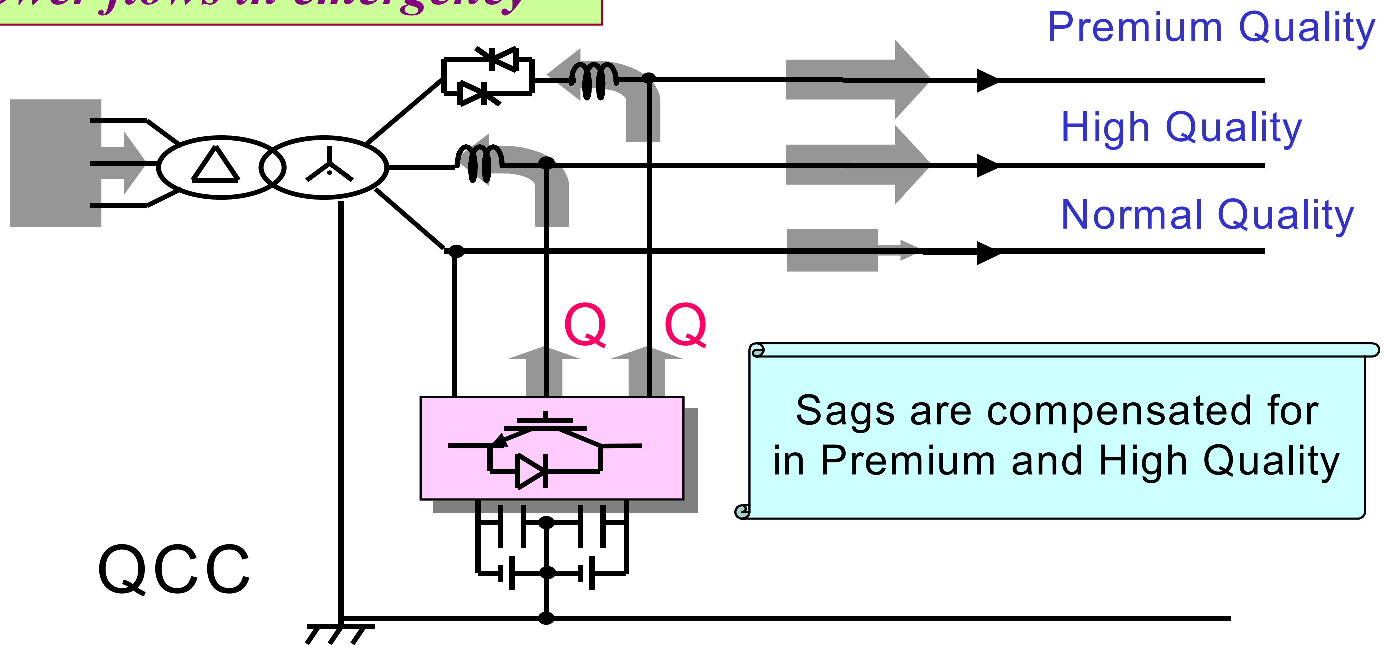
- Flexibel reconfiguration using solid-state switches in QCC
- Multi-quality Power Supply to Customers

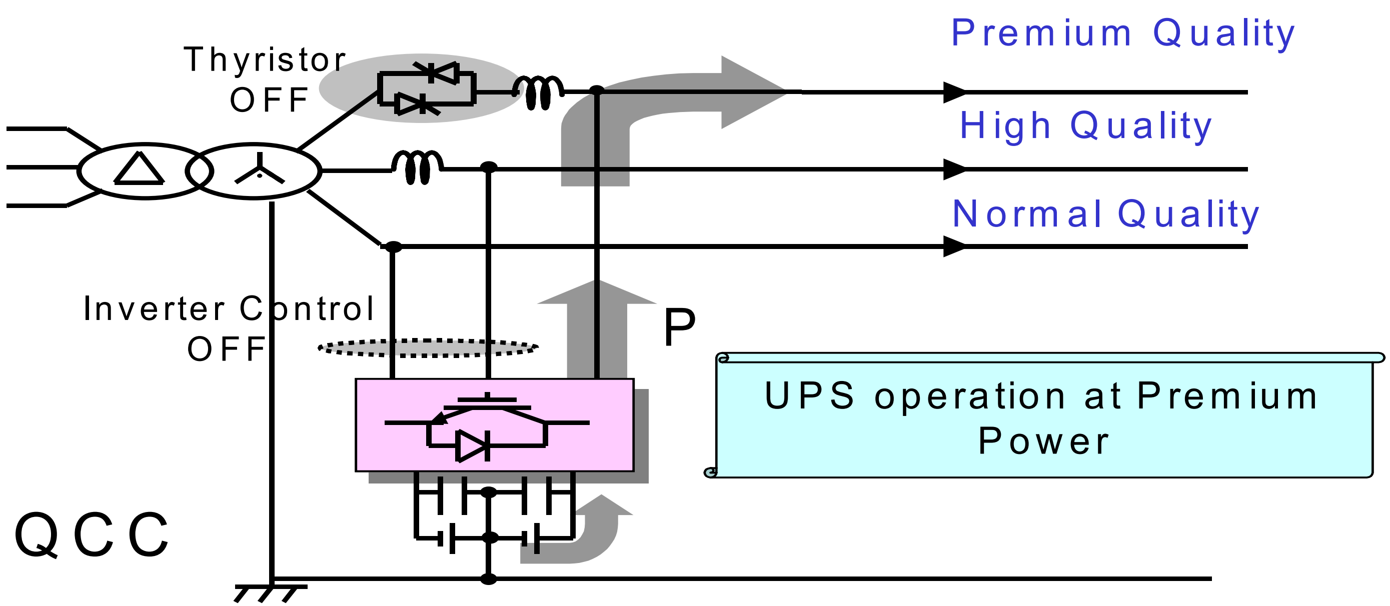
Example of QCC:
Power flow in normal operation



・Compensation of unbalanced power
・Absorption of reverse power

Power flows in emergency

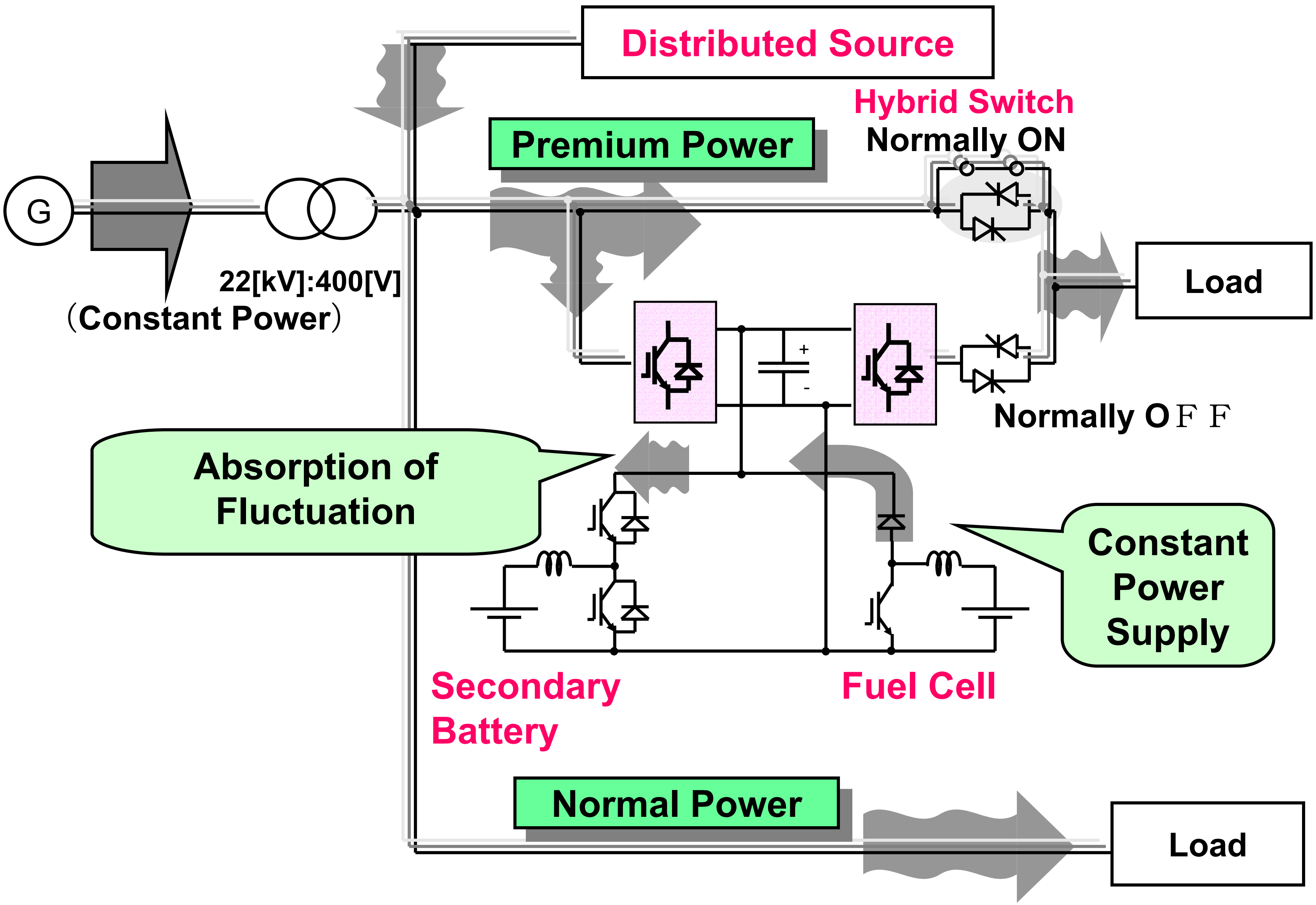




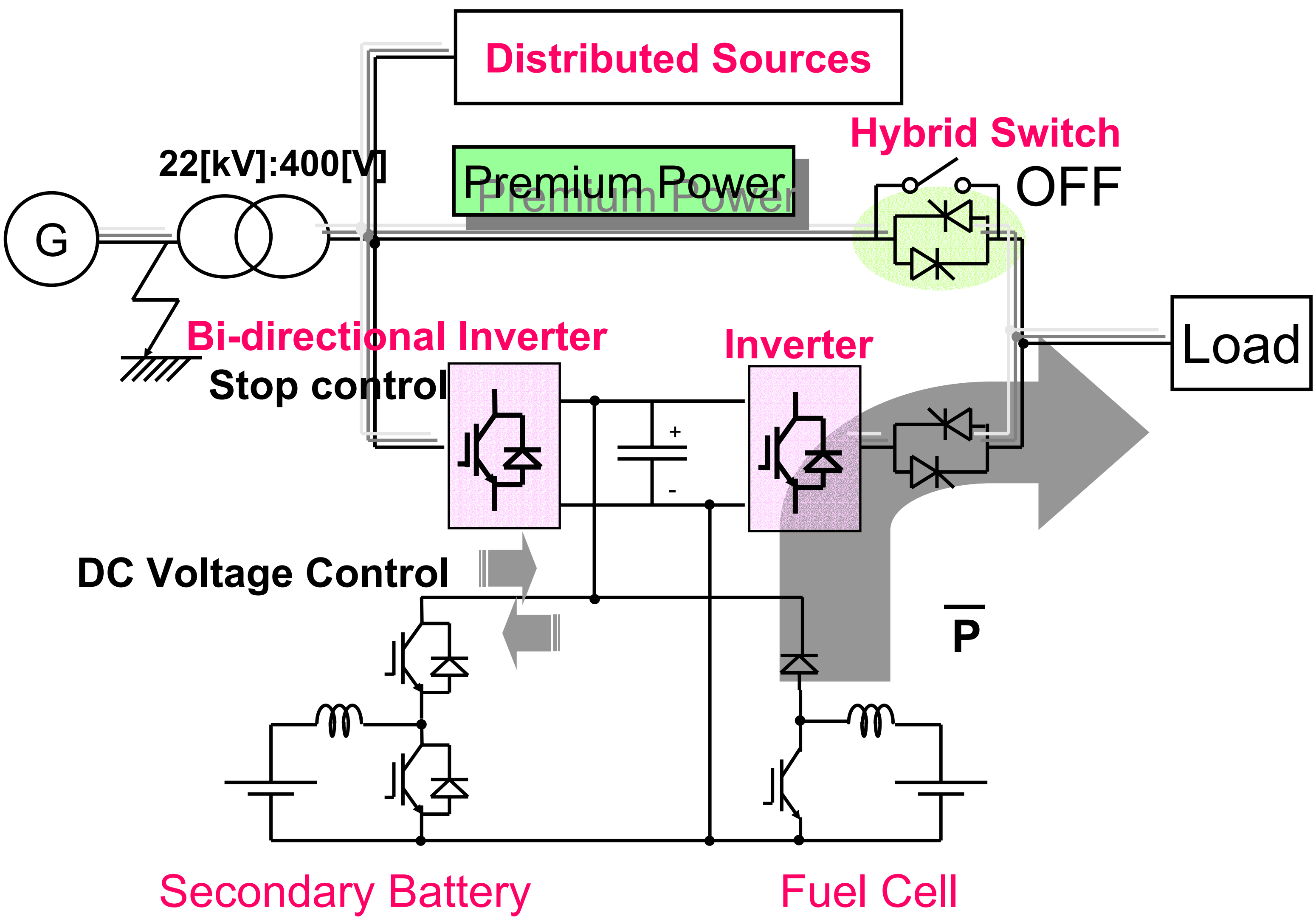
Levels of Power Quality in 3phase4wire System

Events	Normal	High	Premium
Voltage Sags	×	○	○
Voltage Swells	×	○	○
Phase shift	×	×	○
Instantaneous Outage	×	×	○
Short time outage	×	×	○
Long time outage	×	×	×
Unbalance in 3 phase	△	△	△
Flicker	○	○	○
Unbalanced Current	○	○	○
Harmonic Current	○	○	○

Example of QCC:
Power Flows in Normal Operational Condition



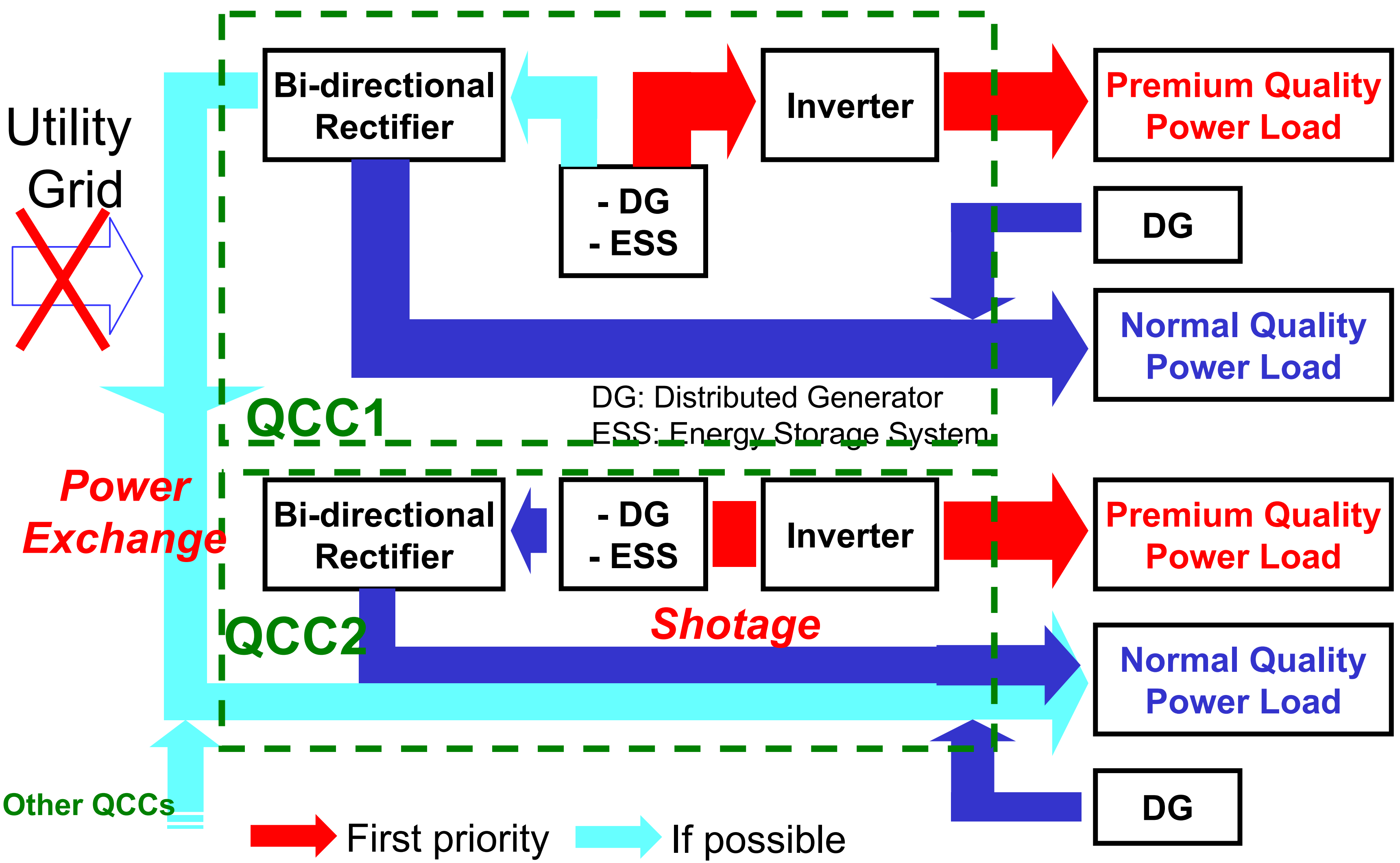
Power Flows in UPS Operation



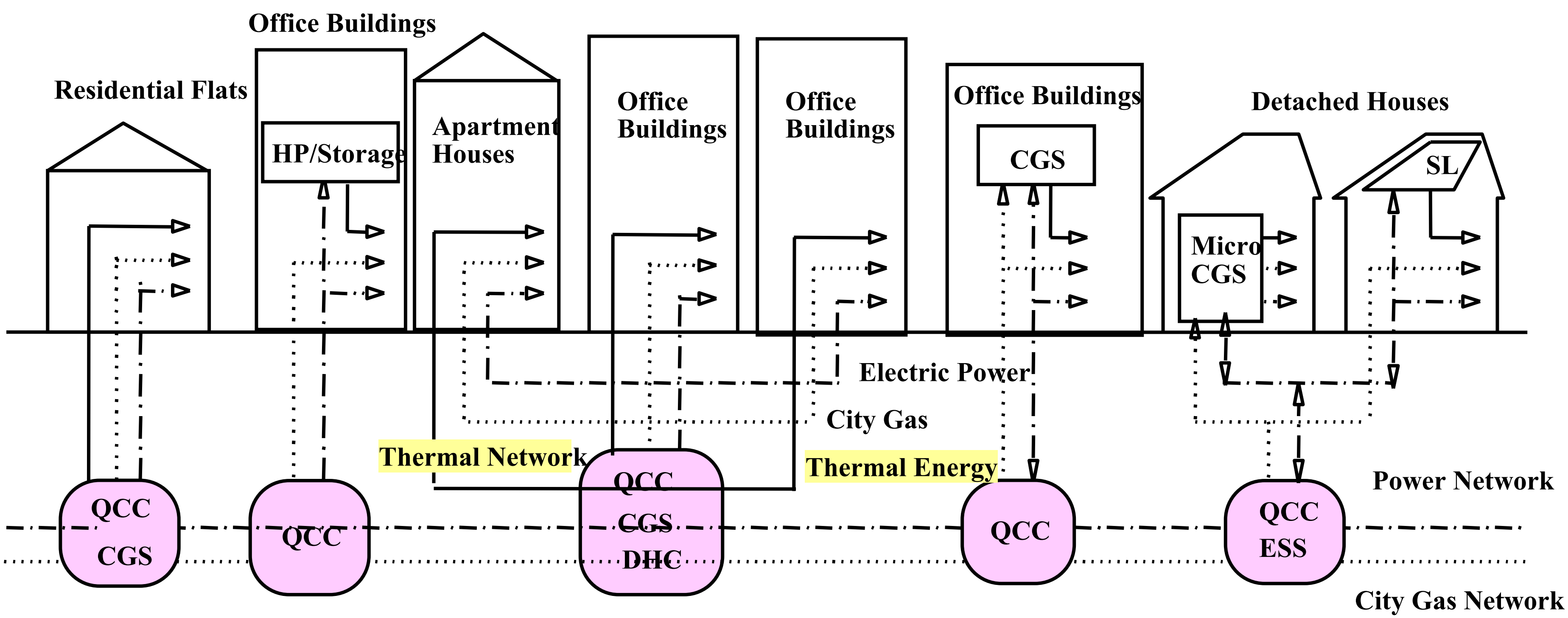
Levels of Power Quality for AC type QCC

Events	Normal	High	Premium
Voltage Sags	×	○	○
Voltage Swells	×	○	○
Phase shift	×	○	○
Instantaneous Outage	×	×	○
Short time outage	×	×	○
Long time outage	×	×	○
Unbalance in 3 phase	×	○	○
Flicker	○	○	○
Unbalanced Current	○	○	○
Harmonic Current	○	○	○

Concept of Power Exchange among QCCs



QCC: Interface with Power Network



QCC: Quality Control Center **CGS**:Cogeneration System **DHC**:District Heating and Coo

ESS: Energy Storage System **HP**: Heat Pump **SL**: Solar energy Utilization System

—·—·— **Electric Power** ········ **City Gas** ——— **Thermal Energy**

Optimization of QCC Allocation

Minimization of Total Cost of Distribution Lines

$$F(\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_n) = (1/2)\int C_i \left(\min \|\boldsymbol{x} - \boldsymbol{x}_i\|^2\right) P(\boldsymbol{x})\, d\boldsymbol{x}$$

$$= (1/2)\sum_{i=1}^{n} \int_{v_i} C_i \|\boldsymbol{x} - \boldsymbol{x}_i\|^2 P(\boldsymbol{x})\, d\boldsymbol{x}$$

where, C_i : (cost of unit power transmission)/(capacity of QCC i)

$\boldsymbol{x}$: location of a load point, (x^1, x^2)

$\boldsymbol{x}_i$: location of QCC i , (x_i^1, x_i^2)

$P(\boldsymbol{x})$: specific load at load point $\boldsymbol{x}$

Optimization of Network

[Objective function]

$$\text{Min.}\quad \alpha\left(\sum_{n=1}^{ND}\left(aX_n + bYN_n\right) + \sum_{m=1}^{BR} c_m YL_m\right) + \beta \sum_{t=1}^{T} Oloss^t$$

Distributed generation cost *Transmission line cost* *Transmission loss*

[Constraints]

(DG's maximum capacity)

$$X_n \in \left\{x^1{}_n, x^2{}_n, \ldots, x^i{}_n, \ldots, x^L{}_n\right\} \left(n = 1, \cdots, ND\right)$$

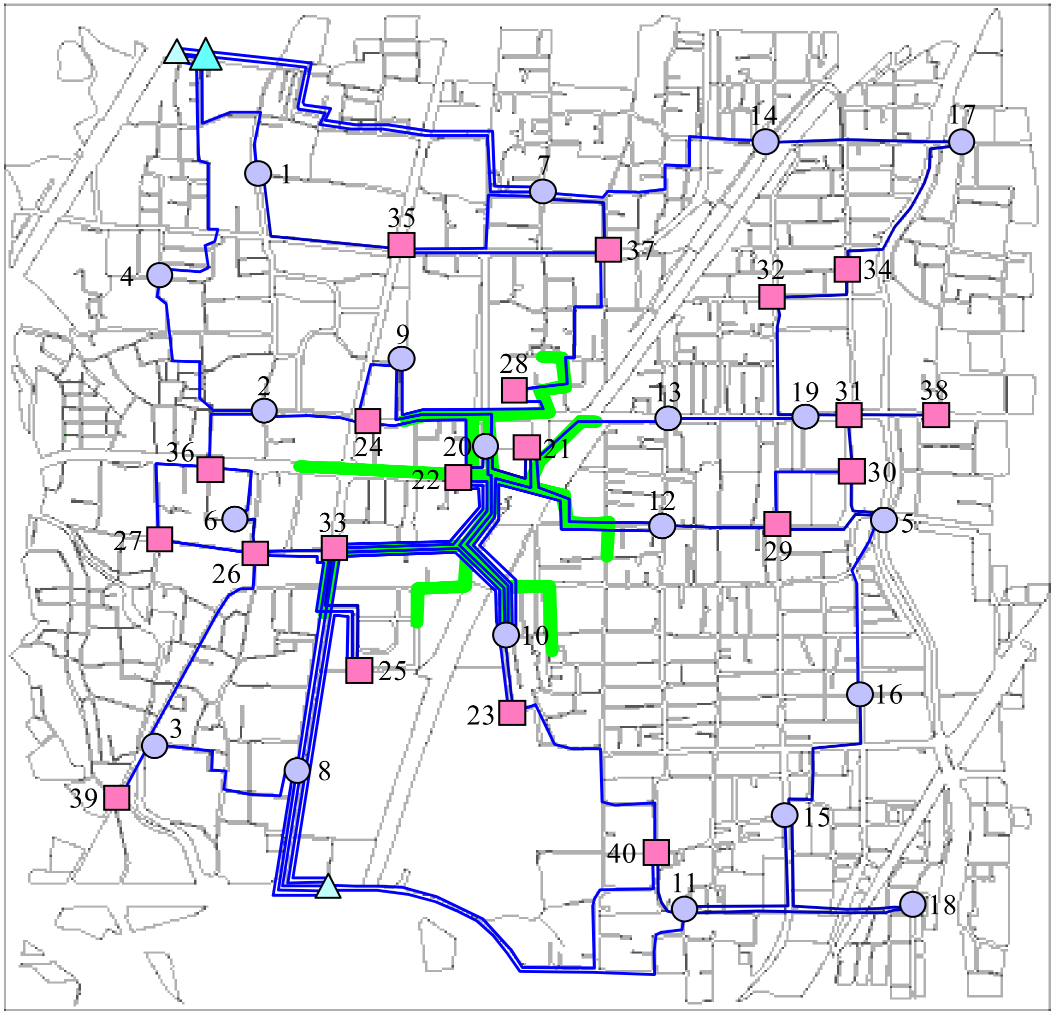
(Expected power interruption cost)

$$\sum_{t=1}^{T} \sum_{r=1}^{FLT} \frac{1}{T} p_r BLCost^{rt} \le \varepsilon$$

(Line power flow capacity)

$$\underline{P_m} \le P_m^{rt} \le \overline{P_m} \quad \left(m = 1, \cdots, BR\right)\left(r = 1, \cdots, FLT\right)\left(t = 1, \cdots, T\right)$$

Possible Image of FRIENDS in the Context of Micro Grid



Prefixed QCC

Location optimized QCC

Utility substation

Thermal network

Distribution network

Concluding Remarks

1) **Energy system optimization for specific area under the CO_2 reduction constraint results in introducing various distributed power generation**

2) **Power distribution network must be redesigned: New concepts are necessary**

3) **FRIENDS is one of the possible forms of micro grid**

   Current status of research:

   - *Various forms and circuits of QCC have been proposed*
   - *Some of the types of QCC have been constructed and tested in lab*
   - *Customized or Unbundled Power Quality Services can be realized*
   - *Power exchange between QCCs have been tested in lab*

Thank you for your attention